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Adjusting WiMAX for a Dedicated Surveillance Network

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ABSTRACT

WiMAX (Worldwide Interoperability for Microwave Access) devices have been used widely in the market. WiMAX-based video surveillance products have also been available. The acceptance of WiMAX in the market, as well as the availability of WiMAX products, contributes to the possibility of implementing it for dedicated video surveillance application. However, since WiMAX is designed to accommodate various applications with different quality of service (QoS) requirements, WiMAX–based dedicated surveillance network may not achieve optimum performance, as all SSs generate the same QoS requirements. The scheduler cannot implement traffic type priority; therefore, service classification does not work as expected. This paper proposes WiMAX adjustment to transform a multi-purpose WiMAX network into a network dedicated to video surveillance. NS-2 simulations show that the proposed adjustment is able to deliver low delay and high quality video surveillance.

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1. INTRODUCTION

Video surveillance applications have experienced an increase in demand over the last decade. Surveillance systems can easily be found not only in places that are sensitive to safety, such as commercial offices, banks and traffic intersections, but also in other areas, such as in parks and recreational areas.

The surveillance technologies have moved from non-real-time systems, where videos are stored and analyzed when unusual situations arise over a given period of time, to intelligent surveillance systems that employ intelligent analysis for real-time image sequencing without human intervention. The invention of digitally-based camera and recording systems has also shifted surveillance systems from using VCR (Video Cassette Recording) to IP surveillance. Although most research fields on video surveillance are dominated by the application layer process, such as motion detection, classification, tracking and behavioral analysis [1], surveillance infrastructure research is important to support efficient and robust surveillance networks [2].

Most current CCTV and IP surveillance systems use coaxial and ethernet cable networks for indoor surveillance. Outdoor surveillance applications rely on wireless LAN and point-to-point radio technologies. Although research on the use of cellular networks for surveillance application exists [3], its real implementation is hardly found due to the limitations of the channel bandwidth.

WiMAX is a wireless broadband technology that offers greater capacity than WiFi networks and wider cell coverage than cellular networks. WiMAX experiences intensive standard development from a fixed broadband wireless application [4]; mobile WiMAX [5], up to standard with 4G capabilities [6]. This makes WiMAX a promising technology for video surveillance infrastructures. Surveillance applications have the potential to be implemented on a WiMAX network, such as multi-surveillance cameras placed on high rooftops in urban areas, high speed point-to-point wireless surveillance, and multi-node rural and mobile surveillance.

WiMAX network is designed for multi-services, ranging from data to real-time applications, and low priority to higher priority. In current WiMAX architecture, a real-time multimedia application is served by rtPS service, which requires QoS negotiation and the enforcement of traffic parameters [7]. When all subscriber nodes are intended for surveillance cameras that generate video traffics, the result is a high network load, over-utilizing rtPS service and under-utilizing other services; consequently, there is a waste of network resources. There is an adjustment requirement in current WiMAX network to be used as an infrastructure for the surveillance network.

This paper addresses the issues mentioned above. The major contributions of this paper are simplified service architecture, packet-aware bandwidth request mechanism and packet-aware scheduling algorithms for dedicated video surveillance application with real-time uniform video traffics. The proposed methods consider the uniformity of the traffic sources.

The rest of the paper is organized as follows. Section 2 surveys the existing works. Section 3 outlines the details of the proposed WiMAX bandwidth allocation architecture, bandwidth request mechanism and scheduling algorithms. Section 4 presents the results of the method's evaluations. Finally, Section 5 concludes the work.

2. RELATED WORKS

Bandwidth allocation in WiMAX comprises two components: bandwidth request mechanism and bandwidth scheduling algorithm. In this section, we briefly describe the existing works on bandwidth request mechanism, followed by the scheduling algorithm

2.1. Bandwidth Request Mechanism

Existing literatures discussed bandwidth request in WiMAX in two forms: modeling the mechanisms and proposing the enhancements. There are various bandwidth request models, such as the slotted Aloha-based model [8]; Queue-based model [9]; Control theory-based model [10]; and Markov Chain-based models [7, 11]. Among the models, the slotted Aloha scheme is the poorest one [11]. The Queue-based models were used for polling-based bandwidth requests which involves queuing, Control theory-based models considers the stability factor and the Markov Chain based models are the most frequently-used models in 802.16 analysis. The models proposed in [7, 11-13] are intended for contention request, the work in [9] is for unicast or polling based request, and literature [12] discussed both bandwidth request mechanisms. In those models, the analysis was performed either in saturated or non-saturated network conditions. Vu, Chan and Andrew [7] emphasized that a saturated condition is important for understanding upper-bound performance. However, Ni, Hu and Vinel [13] considered that networks typically do not operate in saturated conditions.

Besides contention and unicast requests, there is another mechanism known as piggybacking bandwidth request. Literature [14, 16] detailed the bandwidth request mechanism. Contention request with piggyback [14] is a method that rides alongside the bandwidth request for the remaining data into data burst if the allocated bandwidth is not sufficient to carry all data available in the queue. He et al. [15] proposed an analytical model for a contention request with piggyback. Results from [14, 15] show that a contention request with piggyback outperforms the standard contention request.

The improvements to the existing contention-based bandwidth request emphasized the modification of the truncated binary exponential backoff (TBEB). Kwak et al. [16] proposed an exponential increase exponential decrease (EIED)-based contention resolution mechanism for ranging in the WiMAX network. The objective of the EIED backoff algorithm is to minimize the collision probability by randomizing the transmission timing. The contention window (CW) size is adjusted dynamically depending on the collision history; increasing whenever a collision occurs, and decreasing when transmission is successful. The idea was improved by Rajesh and Nakkeeran [17], who enhanced EIED backoff with multi-stage contention resolution (MSCR) for the WiMAX network.-The MSCR reduces the overlapping probability of backoff counters among stations. The Utility Based Backoff (UBB) Algorithm was proposed by Thapa and Shin [18] for initial ranging in the WiBro network. In UBB, instead of using an exponential increment, the CW increment is the function of satisfaction utility of the SS on its deferred backoff value on the previous state. Although those improvements enhance the performance, the methods are not compatible to WiMAX standard.

Improvements to unicast bandwidth requests have been proposed in some literatures [19, 20] for different applications. Mukul et al. [19] proposed a capacity increment on current bandwidth request, which is allocated for the next rtPS traffic. The method performs well when bandwidth is overwhelming; however, the method potentially reduces network performance as the additional bandwidth may be wasted. Liu and Chen [20] proposed an adaptive bandwidth request by adjusting the transmission sequence of the polled traffics. Although the authors claimed the method performed better than the original scheme, it requires a major change to the standard as the slots must be rearranged into contention free and contention period slots.

Pries, Staehle and Marsico [21] proposed and analyzed the performance of contention request, which piggybacks the bandwidth request for the next incoming data into the current data burst. Such piggybacking is appropriate when the traffic has a constant rate, so that the incoming number of bytes is known. Otherwise, the number of requested bytes in a piggyback should be predicted. We call the latter scheme 'next frame piggyback'.

2.2. Scheduling Algorithm

Scheduling algorithms are implementation-dependent and not specified in the standard. The basic legacy scheduler is Round Robin (RR), which examines and allocates bandwidth requests sequentially. The Weighted Round Robin (WRR) and Deficit Round Robin (DRR) modify the RR scheduler by applying different weights that represent node selection frequency. FIFO or FCFS (First Come First Served) prioritizes services based on the earliest arrival time. While the EDF, a well-known scheduling algorithm, prioritizes a node with the earliest deadline, Weighted Fair Queuing (WGQ) uses separate FIFO queues and processes non-empty queues simultaneously. Sophisticated schedulers, such as EDF and WFQ, may not work properly in dedicated surveillance networks as the schedulers work according to different priorities for different traffics, while in dedicated surveillance networks, traffic is uniform.

Dhrona et al. [22] evaluated various scheduling algorithms for uplink (UL) traffic in the WiMAX network. Among the schedulers, Hybrid EDF, WFQ and FIFO produce the highest throughput. Hybrid schedulers, which employ multiple legacy schemes, have also been evaluated in [23, 24]. They perform better than the legacy algorithms as they satisfy the QoS requirements of the multi-class traffic. However, the hybrid scheme is not appropriate to be used in a dedicated surveillance network, as all traffic is video.

Noordin and Markarian [25] classified schedulers into two types: channel-unaware and channel-aware schedulers. Channel-unaware schedulers assume that physical properties are stable. The paper also proposed a strict priority scheduler with minimum bandwidth allocation to avoid bandwidth starving. The scheduler is channel-unaware, but considers indirectly channel quality. Since its priorities are set for different service classes, the scheduler is not suitable for uniform traffic.

A cross-layer scheduler, in contrast, is a channel-aware scheduler. The cross-layer scheduler in [26] obtains parameters from another layer and adjusts them within the current layer. The cross-layer algorithm in [27] employed a priority function at MAC layer and a slot allocation policy at physical layer. It reallocates the slots from the most satisfied user to the most unsatisfied user. Despite the system capacity increment offered by the cross-layer schedulers, the processing time is increased. Since all surveillance nodes intensively send video data, cross-layer schedulers may impose a high processing delay. The dedicated surveillance network is expected to have proper network planning; therefore, poor channel quality in one node may not affect other nodes.

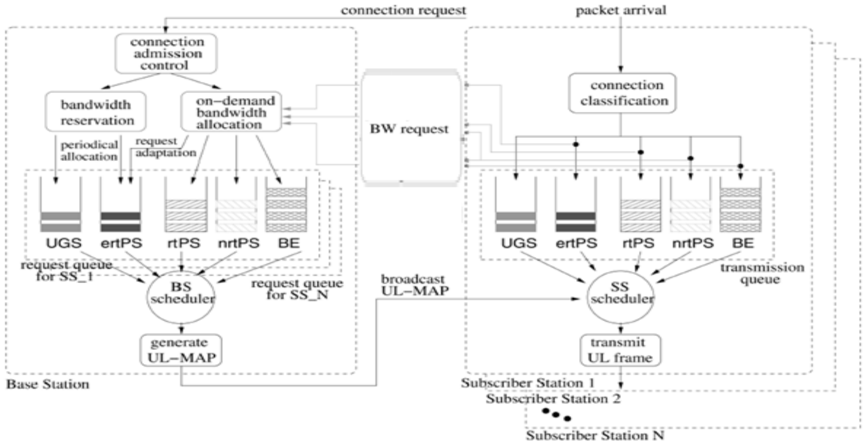
In video streaming, packet types become important as video codec generates frames with different priorities. Packet-aware scheduling for video traffic was introduced in [28, 29]. Kang and Zakhor [28] proposed a scheduling algorithm based on an unequal deadline threshold for wireless video streaming (frame-based scheduling). The SS scheduler increases the deadline from 0 (I-frame) to maximum value (P-frame immediately before I-frame). The frame-based scheduling performs better than EDF for video transmission as I-frame is prioritized. Wang and Liu [29] proposed priority-based EDF, which modified the deadline requirement based on frame type. Basically, the work is similar to [20], except that it considers other traffic classes. Both methods perform similarly in uniform video surveillance, as only one traffic class is involved. The frame and priority-based EDF are sorting schedulers.

3. THE PROPOSED WIMAX ADJUSTMENTS

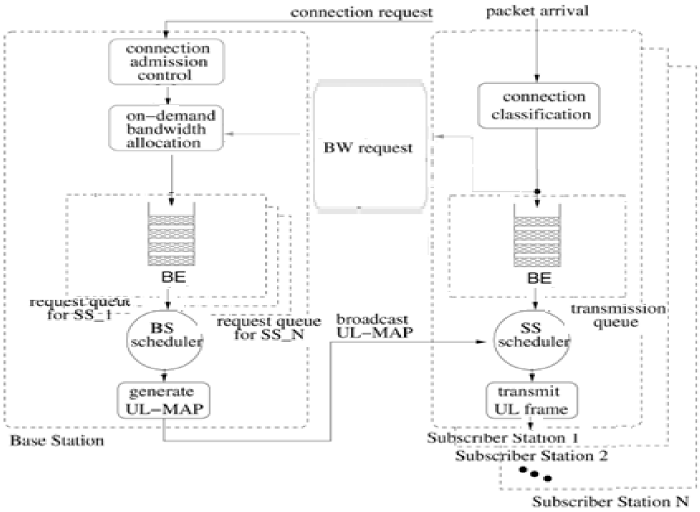
3.1. Flat Service Class Architecture

The assessed WiMAX-based dedicated surveillance network is assumed to use the same bit rate setting in all SS cameras. In such conditions, fairness is achieved when the class of service for all traffics is similar. The Real-time video traffic is served by rtPS in the WiMAX standard. The rtPS service will be maximized, but other services are not utilized. Since rtPS uses unicast request mechanism, BS should poll individually the SSs. The rtPS service also performs additional tasks to determine transmission parameters.

This potentially results in surveillance with rtPS experiencing high delay.



(a). Original architecture, taken with permission from [10]



(b). Simplified architecture

Figure 1. Bandwidth allocation architectures

Figure 1a shows the original architecture in WiMAX standard where various classes of service feed the schedulers. Each service type is bound to the respective bandwidth request mechanism. Since the UGS, ertPS, nrtPS and BE do not have traffic in the examined dedicated surveillance network, the allocated processor power to poll and memory resources for queue in BS and SS schedulers are wasted. We redefine the bandwidth allocation architecture in WIMAX to retain only the BE service (Figure1b). BE is relatively simple to supply as it does not involve QoS negotiation and parameter enforcement [7]. Memory resources in BS are allocated to a single BE queue for each SS and the processor does not perform polling.

3.2. Packet-Aware Bandwidth Request Mechanism

The proposed packet-aware bandwidth request mechanism aims to reduce the delay. It implements two techniques, the reduced contention window to serve traffic from the prioritized frames (I-frames) and next-frame piggybacking to serve the non-prioritized video frames (P-frames and/or B-frames).

3.2.1. The Reduced Contention Window

As mentioned in Section 3.1, there are various techniques proposed to replace the existing truncated binary exponential backoff (TBEB) technique in theWiMAX standard. However, we decided to employ the existing TBEB in the standard, so that the proposed change is more applicable to the existing devices.

The TBEB algorithm determines the random integral number of contending nodes chosen from interval [0, Wi-1]. There will be a significant reduction of contending nodes, since only I-frames require contention bandwidth request. The faster the request is sent, the lower the bandwidth request delay. Therefore, we propose reducing the CW size. We choose a fixed CW size adjustment to avoid unnecessary delays.

The new backoff window size can be assigned as a reduction percentage of P and B-frames: *(ΣP-size+ ΣB-size)/I-size* within one group of picture (GOP). The CW reduction is proposed as the number of contending SSs decreases. However, in order to reduce calculation delay, we simply use a 50% reduction. Therefore, the new random integral number for contending nodes is chosen from the interval $[0, 0.05(W_i-1)]$. If collision occurs, the increment will be $W_i=2^{i-1}W_{i-1}, i\neq0$, where $W_i= 0.5W_i$.

By using the TBEB analysis proposed by Chen and Tseng [14], the probability of a successful request, P_s is a function of the number of available request slots s and the expected number of contending nodes, n_{exp}. That is,

$$P_s = \left(\frac{s-1}{s}\right)^{n_{exp}-1} \qquad (1)$$

where the expected number of contending nodes is defined as

$$n_{exp} = n\frac{n_{tx}}{n_{tf}}\left(1 - e^{-\lambda n_{tf} f}\right) \qquad (2)$$

Here, the rate λ is in distributed Poisson arrival, f is the frame duration, n is the number of SS, and n_{tx}/n_{tf} is the probability that one SS sends a bandwidth request. The average number of requests n_{tx}, and the average request processing time n_{tf}, are functions of the contention window W_i, $i=1,2,..,m$, and collision probability, c.

$$n_{tx} = \sum_{i=1}^{m} i(1-c)c^{i-1} + (m+1)c^m \qquad (3)$$

$$n_{tf} = \sum_{i=1}^{m}(1-c)c^{i-1}\left(\sum_{j=1}^{i}\frac{1}{W_j}\left(\sum_{k=1}^{W_j}k\right)\right) + c^m\left(\sum_{i=1}^{m+1}\frac{1}{W_i}\left(\sum_{j=1}^{W_i}j\right)\right) \qquad (4)$$

The TBEB performance for the arrival rate and CW reduction is depicted in Figure 2. If we assume initial arrival rate and contention window λ=120 and Wo=8, the replacement of P-frames bandwidth request using next frame piggyback reduces the arrival rate. The TBEBs for reduced arrival rates (λ=100 and λ=80) produce higher successful probability than TBEB with λ=120. Arrival rate and CW reduction from 8 to 4 provide more improvement in the successful probability.

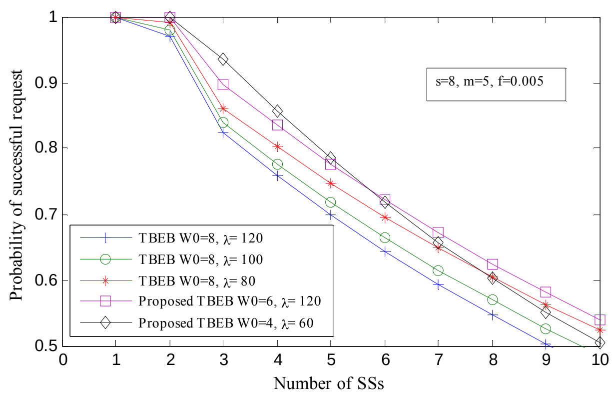


Figure 2. Performance of TBEB.

Although the proposed TBEB performance degrades when the number of SSs increases, we assume that the surveillance works on a non-saturated network with an acceptable maximum number of SSs.

3.2.2. Next-Frame Piggyback

The next-frame piggyback method serves traffics from the P-frames. The method allocates the bandwidth request for the next frame n+1 in burst of frame n as discussed in [21]. However, the capacity of the next frame n+1 is predicted, as the size of frame n+1 is unknown when sending frame n.

If the number of bytes in current queue is B_n, the allocated bandwidth is B'_n and the predicted next frame byte is B'_{n+1} then the piggybacked request byte is:

$$PB_n = (B_n - B'_n) + B'_{n+1} \tag{5}$$

Since the value of B'_{n+1} is predicted, there is a chance that the predicted bytes are less or more than the actual ones. If we rewrite Equation 4.6 for the next frame request to $PB_{n+1}=(B_{n+1} - B'_{n+1})+B'_{n+1}$, the first right part determines whether the allocated bandwidth satisfies the SS need. If $B_{n+1} - B'_{n+1} = 0$, then the allocated bandwidth is precisely as required by SS. However, if $B_{n+1} - B'_{n+1} > 0$, the allocated bandwidth is less than bytes in the SS queue. Data will be sent in more than one burst, which potentially generates higher delay and jitter. However, if $B_{n+1} - B'_{n+1} < 0$, then the allocated bandwidth is higher than the available data. Consequently, $B_{n+1} - B'_{n+1}$ bandwidth is wasted.

3.3. Packet-Aware Non-Sorting Schedulers

The sorting schedulers, such as EDF and WFQ, populate all connections from nodes that have bandwidth request. Then, the schedulers sort the list of connections based on particular parameter. The sorting process generates delay and may postpone grant in the nearest uplink opportunity, which, in turn, increases delay. According to Puschner [30], the average time complexity of sorting algorithms, such as bubble sort and insertion sort, is quadratic in the number of elements. For example, selection sort requires 1.40, 4.81, and 26.6 time units for sorting 5, 10, and 25 elements, respectively.

The proposed schedulers employ the O(1) non-sorting schedulers: RR and FIFO as the base. The schedulers consider processing time and transmission delay for high-capacity requests, such as I-frames to avoid a frame to be transported in different bursts. Sending one frame in separated bursts may result in high delay and loss; therefore, the proposed schedulers prioritize important frames and avoid sorting process.

3.3.1. RR-Based Scheduler

The RR-based packet-aware non-sorting scheduler works as follows. BS checks whether a node has made a bandwidth request. If the request exists and the bandwidth is for a prioritized frame, a bandwidth allocation decision is made directly. However, if the bandwidth request is for non-prioritized frame, the request will be suspended temporarily. If all nodes have been checked, the suspended requests are then processed and bandwidth requests are allocated. The proposed algorithm is shown in Figure 3.

Proposed RR based packet aware non-sorting scheduler

```
begin
    for i=0 to n-1 do
        Begin
            if (node[i].BWrequest>0 && frame == 'I') then
                UL-MAP←Allocate (node[i].BWrequest.length);
            else if (node[i].BWrequest>0 && frame ≠ 'I') then
                BWarray←Allocate (node[i].BWrequest.length);
        end;
        if (i == n-1 && BWarray.length>0) then
            for j=0 to BWarray.length-1 do
                Begin
                    UL-MAP←Allocate (BWarray[j].length);
                end;
    return UL-MAP;
end;
```

Figure 3. RR based packet-aware non-sorting scheduler

3.3.2. FIFO-Based Scheduler

FIFO scheduler processes bandwidth requests based on the earliest arrival time. For each request received by BS, if the requested bandwidth is for the prioritized frames, a bandwidth allocation decision is made directly. But if it is from non-prioritized frames, the request will be suspended. If there is no subsequent request from the last node served, the scheduler checks the next node. If the total number of requests and the checked SSs is equal to the number of registered SSs, the suspended requests are processed and bandwidth requests allocated. The proposed scheduler is shown in Figure 4.

Proposed FIFO based packet aware non-sorting Scheduler

```
begin
    for i=0 to n-1 do
        begin
            If (Request.exist==true) then
                node[i]=Request.first.node();
                Request.removefirst;
            if (node[i].BWrequest>0 && frame == T) then
                UL-MAP←Allocate (node[i].BWrequest.length);
            else if (node[i].BWrequest>0 && frame ≠ T) then
                BWarray←Allocate (node[i].BWrequest.length);
        end;
        if (i == n-1 && BWarray.length>0) then
            for j=0 to BWarray.length-1 do
                Begin
                    UL-MAP←Allocate (BWarray[j].length);
                end;
    return UL-MAP;
end;
```

Figure 4. FIFO-based scheduler algorithm

4. EVALUATION METHOD

To evaluate the proposed methods, we employ NS-2 simulator with NIST WiMAX module. The WiMAX transmit power and receiver threshold were set to provide 1000 m coverage radius. The modulation scheme was 64 QAM, with a two-ray ground propagation model. The simulated surveillance had 4 mobile nodes (MN) within one base station. Each node had a different speed as shown in Figure 5.

The traffic sources were generated from an MPEG video: akiyo_cif.yuv. Its video trace was used as simulated traffic in the NS-2 simulations, where the received patterns were reconstructed based on the original video. The MPEG4 video codec was chosen simply for the readily-available MPEG4 traffic generation, reconstruction and evaluation framework for the NS-2 simulator. Packet delay and video quality are the main measured parameters.

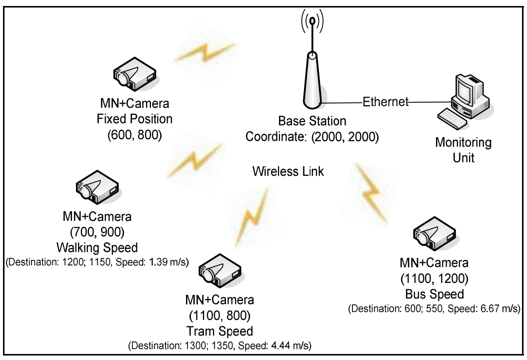


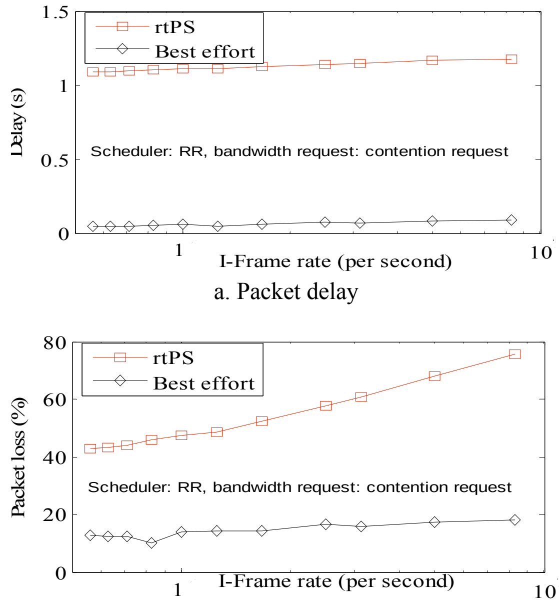
Figure 5. Simulation configuration

First, we evaluated the performances of the proposed flat BE service architecture and compared it with the standard architecture with rtPS for uniform surveillance traffic. Afterwards, the proposed bandwidth request mechanisms are examined using previous architecture. Finally, we evaluated the proposed schedulers and compared them with RR, FIFO, EDF and frame-based schedulers using the previous proposed methods.

5. RESULTS AND ANALYSIS

5.1. Performance of the Flat BE Service Architecture

Figure 6 demonstrates the performance comparison between the proposed BE service architecture and the standard rtPS service in terms of delay and packet loss. Since the evaluated traffic has similar requirements (video traffic), rtPS requires BS to poll all SSs. The polling system should catch the strict timing of the UL-sub-frame. When rtPS polling misses the closest DL-MAP, SS is late receiving bandwidth grant, which leads to long queue in the SS buffer. As a result, data could be sent in more than one data burst, which causes high delay and potentially experiences high packet loss.



a. Packet delay

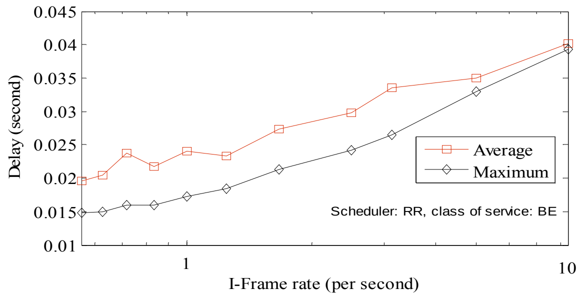
b. Packet loss

Figure 6. Performance of BE vs rtPS

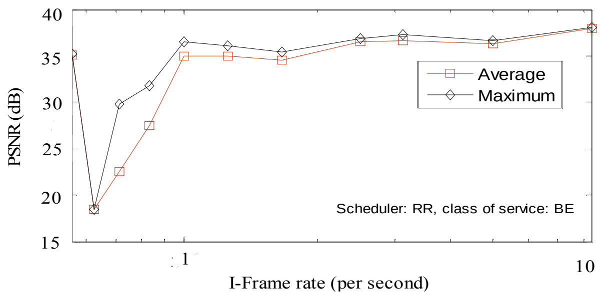
In contrast, BE service allows SS to contend any time to send data. Since BS allocate K-slots of its UL-sub-frame for contention, the opportunity to send data successfully is greater than waiting to be polled. In average, BE service experiences 1.06s lower delay and 38% lower packet loss than RtPS.

5.2. Analysis of Bandwidth Request Mechanisms

The performance of the proposed bandwidth request mechanism for P-frames is affected by the piggybacked byte prediction. Figure 7 shows that the maximum P-frame size prediction exerts lower delay than that using the average values. The greater the bandwidth allocated, the more opportunities there are to send data. Consequently, sufficient bandwidth allocation reduces packet loss and improves video quality. Maximum prediction results have better PSNR than the average prediction. Although PSNR experiences irregularity when GOPs are 30 to 40, this may be caused by the received video suffers from high non-decodable frames, which makes PSNR values drop to about 18dB. The occurrences were repeated in other experiments, which show that GOP values from 30 to 40 are sensitive to packet loss.



a. Packet delay



b. PSNR

Figure 7. Performance of the predicted next frame piggybacking

Figure 8 presents the delay performances of unicast polling and contention request [4], contention request with piggybacking [14], next-frame piggybacking [21] and the proposed bandwidth request mechanism with a constant predicted value of 3500 bytes. This value is chosen from the average and maximum P-frame sizes.

The proposed bandwidth request is aimed to reduce packet delay. The evaluation shows that the method has the lowest delays for almost all I-frame rates. The main reason is that the proposed method has lower request contenders than contention request and piggybacking methods as only I-frames take the request opportunities. Consequently, the successful probability of the request is higher, which leads to fewer delays.

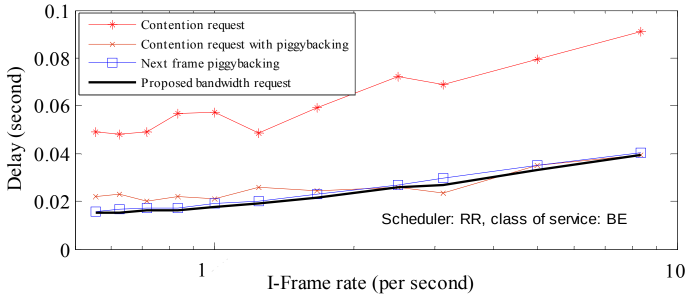
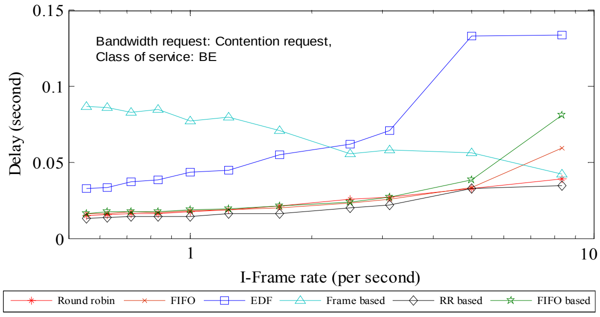


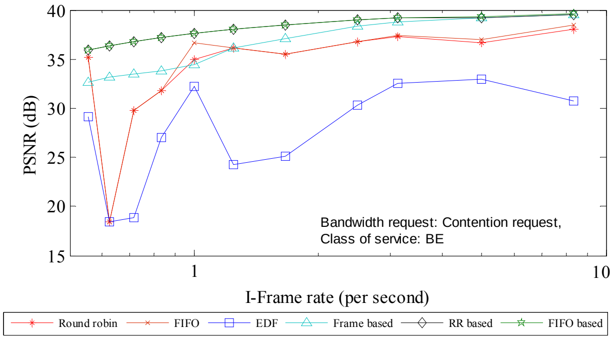
Figure 8. Delay performance of bandwidth request mechanisms

5.3. Analysis of Scheduling Algorithms

Since the proposed schedulers are packet-aware schedulers, we compared them with the frame-based scheduler [28]; a state of the art packet-aware scheduler. Although priority-based EDF [29] is also a packet-aware scheduler, it is similar to [28] for SSs with similar traffic requirements. The proposed schedulers are non-sorting schedulers; therefore, we also compared them with EDF as being representative of sorting schedulers. The scheduler performance assessment was conducted by using the proposed bandwidth request mechanism.



a. Delay



b. PSNR

Figure 9. Performance of scheduling algorithms

Figure 9 depicts the scheduler performances using the proposed bandwidth request mechanism. The proposed scheduler outperforms the existing schedulers for both delay and PSNR. The proposed schedulers are able to achieve the highest PSNR because they allocate the entire prioritized packets in the first place. Although FIFO-based scheduler delay is greater than RR and FIFO for higher I-frame rates, its video performance is much better than both schedulers. Frame-based scheduler delay decreases if I-frame rate increases. Since it prioritizes I-frames with zero deadlines, the sorting process is much easier when traffic has more I-frames. Consequently, it produces slightly lower PSNR than the proposed schedulers. In contrast, EDF experiences the highest delay and the worst PSNR. The deadline stamping does not work for uniform traffic because all traffic has similar deadline requirements. The possibility of I-frames being transported in separated bursts increases, which worsens latency and degrades PSNR.

The irregularity of PSNR values in Figure 9, which drops to about 18dB, may be caused by consecutive packet losses. These losses make the received frame un-decodable and consequently, the average PSNR values dropped to the lowest figure.

6. CONCLUSION

This paper proposed flat BE service architecture, bandwidth request mechanism and scheduling algorithms to adjust WiMAX to be used for surveillance network. The architecture optimizes BS resources. Following the architecture, we proposed a packet-aware bandwidth request mechanism using reduced CW and piggybacking methods. Finally, RR and FIFO-based non-sorting schedulers were proposed.

The evaluation shows that our proposed techniques outperform the existing methods. Best-effort service is more suitable for WiMAX with all SSs generating similar video traffic to the rtPS service. BE, with the proposed architecture, is able to improve significantly the overall performance. The proposed bandwidth request is also able to reduce bandwidth request delay. Both RR and FIFO-based packet-aware schedulers are able to improve PSNR values of the received video.

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